THIN-TARGET BREMSSTRAHLUNG

CODE DOCUMENTATION

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Description

This program, BREMSPEC, computes the bremsstrahlung x-ray/gamma-ray spectrum from the interaction of energetic electrons with a uniform, thin-target plasma. The photon flux in photons sec^{-1} keV^{-1} cm^{-2} is computed as a function of photon energy. Angular dependence of the electron distribution function and radiation is not included. Therefore, both are assumed to be isotropic.

To run the program, the following files must be compiled and linked:

> bremcross.for
> bremspec.for
> dmlinbr.for
> fdblplbr.for

The IDL routine BREMPLOT.PRO reads and plots the output from BREMSPEC. Photon flux is plotted as a function of photon energy in keV.

The photon flux at energy E_{ph} is computed from the equation

$$Flux = \frac{nNV}{4\pi(AU)^2} \frac{1}{(mc^2)^2} \int_{E_{ph}}^{E_{eHigh}} f(\gamma)\frac{p}{m}\sigma(E_{ph}, E_{el})dE_{el}$$

Here n and N are the number densities (cm^{-3}) of the thermal plasma and energetic electrons, respectively. V is the volume of the emitting region and AU is one astronomical unit (in cm), taken to be the distance from the source to the detector. The mass of the electron and the speed of light are m and c, respectively, and mc^2 is the rest mass energy of the electron in keV.

The integral is over electron energy, E_{el} (in keV). E_{eHigh} is the maximum energy of the radiating electrons. The electron distribution function is $Nf(\gamma)$, where γ is the relativistic gamma factor, related to the electron (kinetic) energy through $E_{el} = (\gamma-1)mc^2$, and $f(\gamma)$ is normalized so that

$$\int_{\gamma_{Low}}^{\gamma_{High}} f(\gamma)d\gamma = 1$$

The remaining terms in the integrand are p, the electron momentum, and $\sigma(E_{ph}, E_{el})$, the bremsstrahlung cross section. The cross section is from equation (4) of E. Haug, Astron. Astrophys. 326, 417 (1997). This cross section closely follows the relativistic cross section of Bethe and Heitler, equation 3BN in H.W. Koch and J. W. Motz, Rev. Mod. Phys. 31, 920 (1959), but requires fewer computations. The multiplicative Elwert correction to the Born approximation (G. Elwert, Ann. Physik 34, 178, 1939) is included in the cross section.

The integration is performed by Function DMLIN using Gaussian quadrature. This function and Subroutine GAULEG in the file dmlinbr.for are adapted from Press et al., Numerical Recipes in Fortran 77, Second Edition (Cambridge University Press, 1992). The input variable RERR determines the fractional error in the integration steps.

A double-power-law electron distribution function is provided by Subroutine DISTRN in the file fdblplbr.for. To facilitate the numerical integration when the photon energy, EPH, is less than the double-power-law break energy, EEBRK, BREMSPEC performs the integration in two parts, above and below EEBRK (or, equivalently, GAMBRK) and sums the parts.

Contact

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Input Parameters

All input parameters are specified in Program BREMSPEC.

EELOW   Low energy cutoff in the electron distribution
                                         function (in keV)

EEBRK   Break energy in the electron distribution function
                                         (in keV)

EEHIGH   High energy cutoff in the electron distribution
                                         function (in keV)

P   Power-law index of the electron distribution
                                         function below EEBRK

Q   Power-law index of the electron distribution
                                         function above EEBRK

Z   Mean atomic number of the target plasma

DENSTY   Number density of nonthermal electrons (cm^{-3})

NTH   Number density of plasma ions (cm^{-3})

VOLUME   Volume of the radiating source region (cm^3)

RERR   Desired relative error for evaluation of the integral.
                                         For example, RERR = 0.01 indicates that the
                                         estimate of the integral is to be correct to one digit,
                                         whereas RERR = 0.001 calls for two digits to be
                                         correct.

EPH   Photon energies (in keV) at which to compute the
                                         photon flux, specified in a DO loop.

Output Parameters

EPH and FLUX are written to the file output.txt. EPH, IERGQL, and IERGQH are written to the file error.txt. All four of the output parameters are written to the screen as the program runs.

EPH   Photon energy in keV

FLUX   Photon flux at photon energy EPH in photons s^{-1} keV^{-1} cm^{-2}. The detector is assumed to be 1 AU from the source.

IERGQL   Error flag from the Gaussian quadrature integration routine for integration over electron energies below EEBRK. The numerical integration converged if IERGQL = 0. It did not converge if IERGQL = 120.

IERGQH   Error flag from the Gaussian quadrature integration routine for integration over electron energies above EEBRK. The numerical integration converged if IERGQH = 0. It did not converge if IERGQH = 120.

Subprograms

Program BREMSPEC — Specifies all input parameters, calls DMLIN to compute the photon flux for all photon energies, and writes the results to the screen and files.

Function FTHIN — Computes the integrand for the numerical integration. Calls DISTRN and BREMCROSS. The normalization coefficient (FCOEFF) is computed in Program BREMSPEC.

Subroutine BREMCROSS — Computes the bremsstrahlung cross section as a function of Z, incident electron energy (EEL), and radiated photon energy (EPH).

Subroutine DISTRN — Computes the normalized electron distribution function, $f(\gamma)$. A double-power-law distribution function is provided.

Function DMLIN — Performs the Gaussian quadrature numerical integration. Repeatedly doubles the number of points evaluated until convergence, specified by RERR, is obtained or the maximum number of points, specified by the parameter MAXFCN, is reached. IER = 120 is returned if the integration fails to converge. MAXFCN should be less than or equal to 2**NLIM, or 4096 with NLIM = 12.

Subroutine GAULEG — Computes the Gaussian quadrature abscissas and weights for Function DMLIN. Adapted from Press et al., Numerical Recipes in Fortran 77, Second Edition (Cambridge University Press, 1992).